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WIND TUNNEL MEASUREMENTS OF VERTICAL ACTING LIMB FLAIL FORCES AND TORSO/SEAT BACK FORCES IN AN ACES-II EJECTION SEAT

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JUNE 1976

AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
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FOR THE COMMANDER

HENNING E. VON GIERKE
Director
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In the study of flail injury (References 4 and 5) it is important to know the magnitude of the forces tending to pull a crew member's limbs away from their "stowed" position, when he first ejects into the windblast. Earlier wind tunnel studies did not record the limb lift component force for the hands or feet. These forces, along with the drag force between the occupant and the seat, were measured in this investigation, for the range of pitch and yaw angles used in the previous investigations of other force components. The

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20. Abstract (Continued)

results and their implications are presented and discussed.

PREFACE

This report was prepared in partial fulfillment of Contract Number F33615-75-C-5096. The research was accomplished by Payne, Inc., 1910 Forest Drive, Annapolis, Maryland 21401. Peter R. Payne was the Principal Investigator.

The Air Force Technical Monitor was James W. Brinkley of the Impact Branch, Biodynamics and Bionics Division of the Aerospace Medical Research Laboratory. The work was performed in support of Project 7231, "Biodynamics of Aerospace Operation", Task 723106, "Impact Exposure Limits and Personnel Protection Criteria."

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INTRODUCTION

In the study of flail injury (References 4 and 5) it is important to know the magnitude of the forces tending to pull a crew member's limbs away from their "stowed" position, when he first ejects into the windblast. The general background to the problem has been discussed by Payne (Reference 3) and some experimental measurements are reported in References 1, 2 and 3. Those measurements did not record the lift force on the hands or feet. They also did not measure the difference between the drag force on the torso and seat structure. An ACES-II ejection seat that had a large data base of wind tunnel tests with human subjects was therefore modified to measure these forces.

Test Facilities and Equipment

The University of Maryland subsonic wind tunnel is of the single return type with a rectangular working section 7.75 feet high by 11.04 feet wide. The tunnel is vented at the working section to ambient pressure, establishing the pressure reference datum. Dynamic pressure ($q = \frac{1}{2}\rho u^2$) at maximum tunnel operating speed is 135 lb/ft^2, corresponding to a speed of 337 ft/sec.

The tunnel is particularly suitable for tests with live subjects, since the test section accommodates a human figure, plus ejection seat, for less than 10% blockage and with adequate clearance above and below. The section is well lighted and has glass viewing panels on either side and above, so that the subject is under observation from the control room and additional vantage points. Details of the tunnel and the way in which it is used for limb flail tests may be found in References 1, 2, and 3.

Local Force and Pressure Measurements

The tunnel instrumentation provided 58 automated data channels, including ten galvanometer systems linear to 600 Hz. Eight of these channels were used to record limb and torso forces from strain-gauged beams mounted on the seat assembly. The measurements on these channels were automatically punched on IBM cards. Any six channels on this system could be switched to dynamic recording, linear to 150 Hz, when examination of transients in real time were required.

ACES-II Ejection Seat Modifications

The modifications to the existing ACES-II ejection seat were:

1. The ejection handles were positioned to accept strain-gauged beams to measure the lift force component (body axes) (Figure 1).

2. The feet supports were altered to accept strain-gauged beams to measure the lift force component (body axes). Figure 2.

3. A liner was constructed to fit within the ACES-II Seat and supported in such a manner that all the drag loads would be measured independently of the main ACES-II seat (body axes). Figures 3, 4, 5 and 6.

Test Procedure

These tests were run at a dynamic pressure of 20 pounds per square foot (129.7 ft/sec). The pitch angle is set and the tunnel balance automatically positions the subject at a given yaw angle. The prescribed forces are recorded digitally from the strain-gauged beams whose relative positions are shown in Figure 7.

All of the strain gauges were statically calibrated just prior to the test run. The Wheatstone bridge circuits were periodically shunted to see if there had been any damage to the circuits during the tests. Finally, all data was recorded as force areas, that being the measured force divided by the dynamic pressure ($C_f = F/q$).

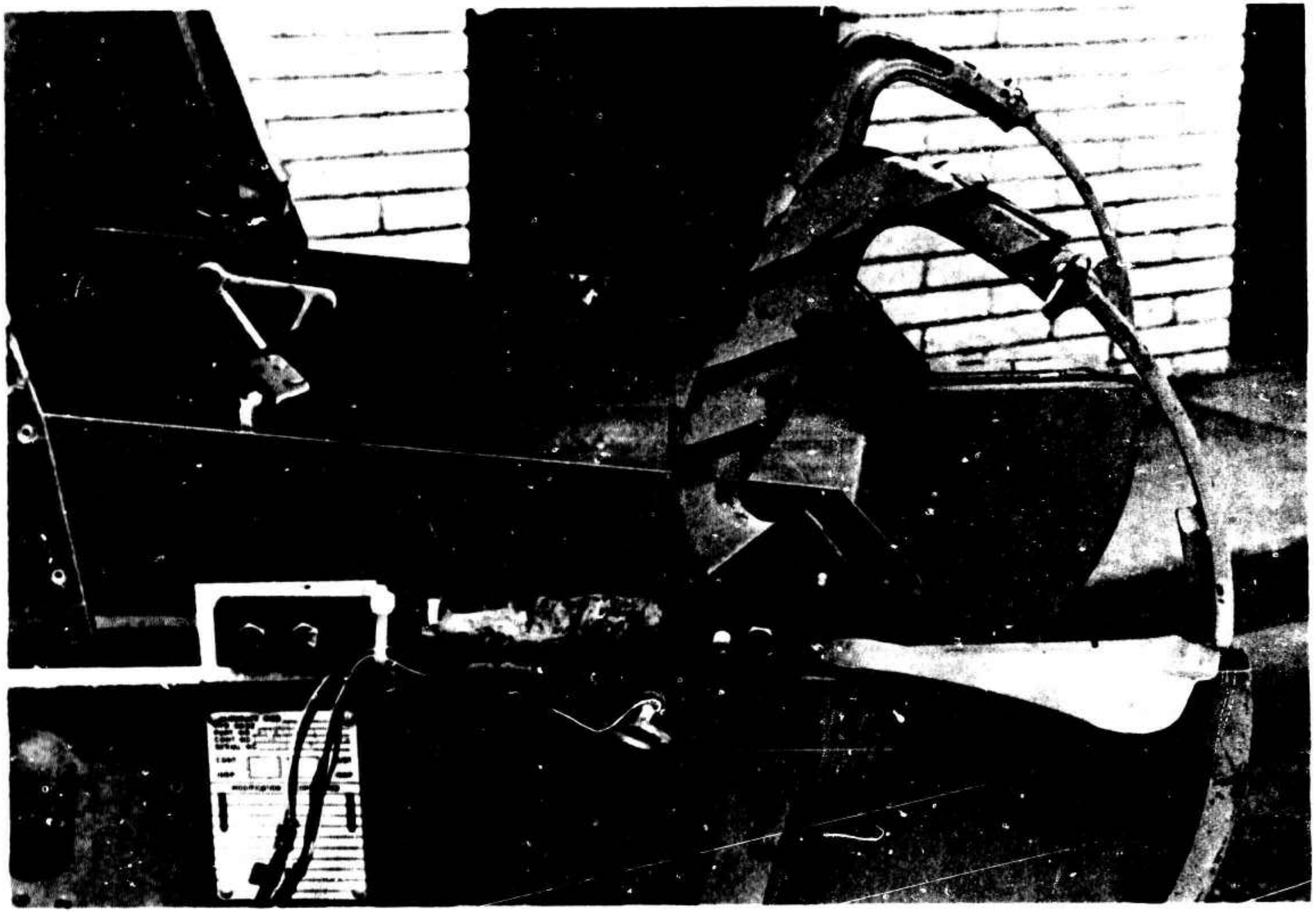


FIGURE 1. VIEW OF RIGHT EJECTION HANDLE AND STRAIN-GAUGED BEAM FOR MEASURING VERTICAL HAND LOADS.

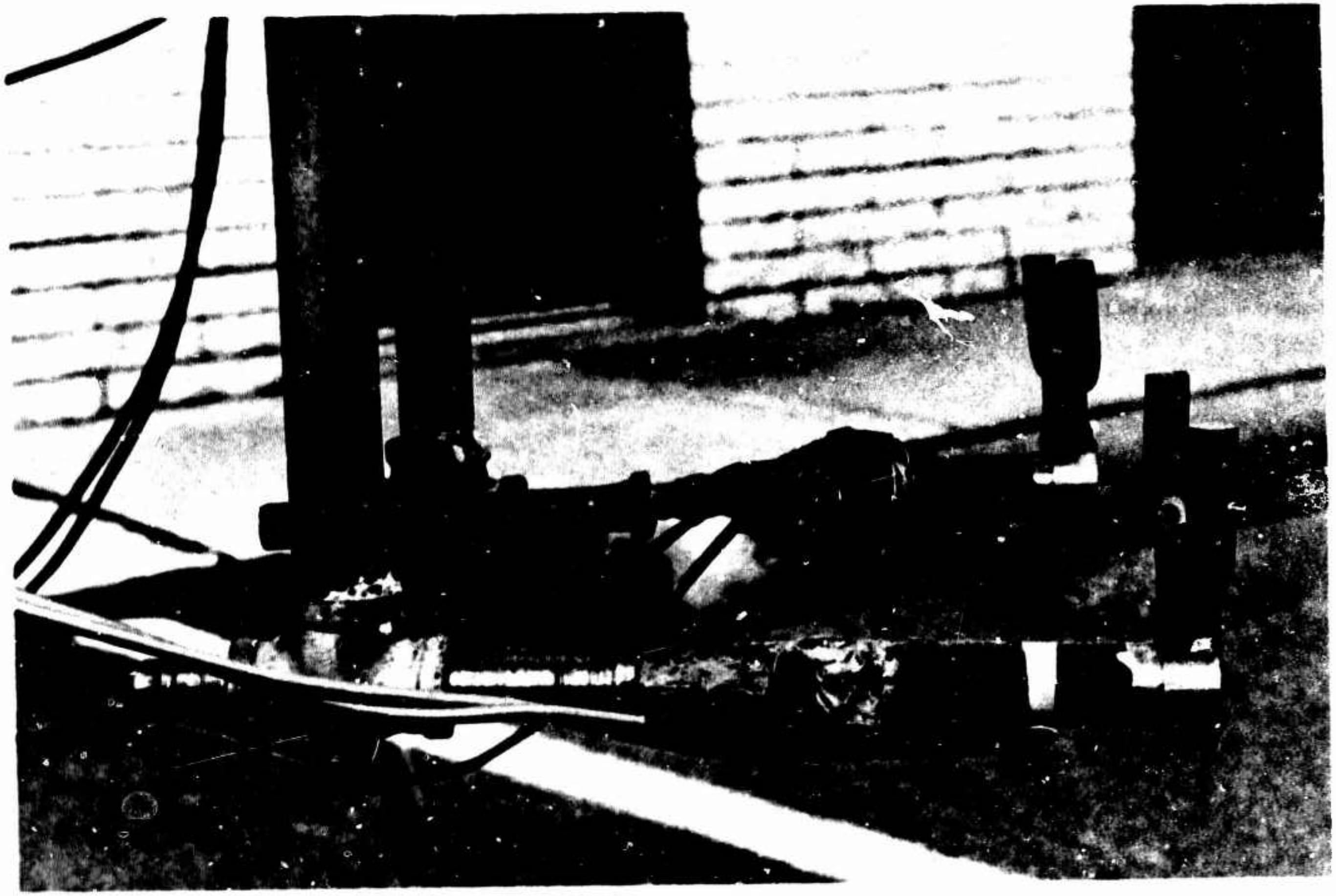


FIGURE 2. VIEW OF FOOT SUPPORTS AND STRAIN-GAUGED BEAM FOR MEASURING VERTICAL FOOT LOADS.

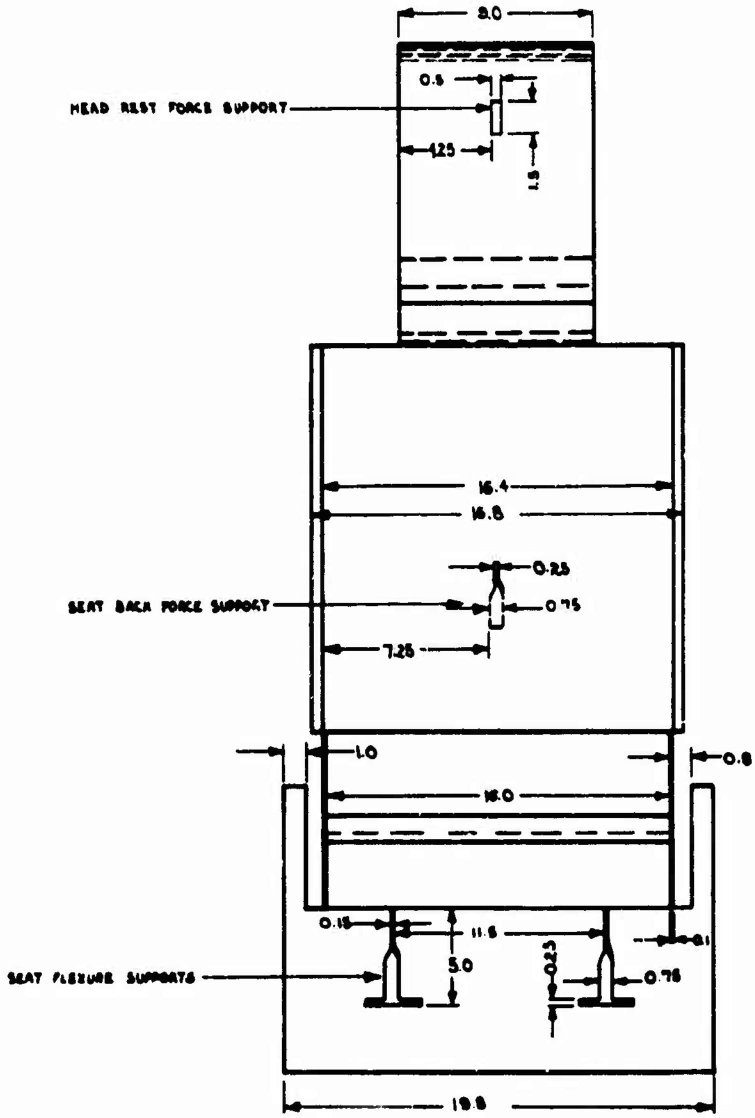


FIGURE 3(A). FRONT ELEVATION VIEW OF AN ACES-II EJECTION SEAT "LINER." THE DIMENSIONS ARE IN INCHES.

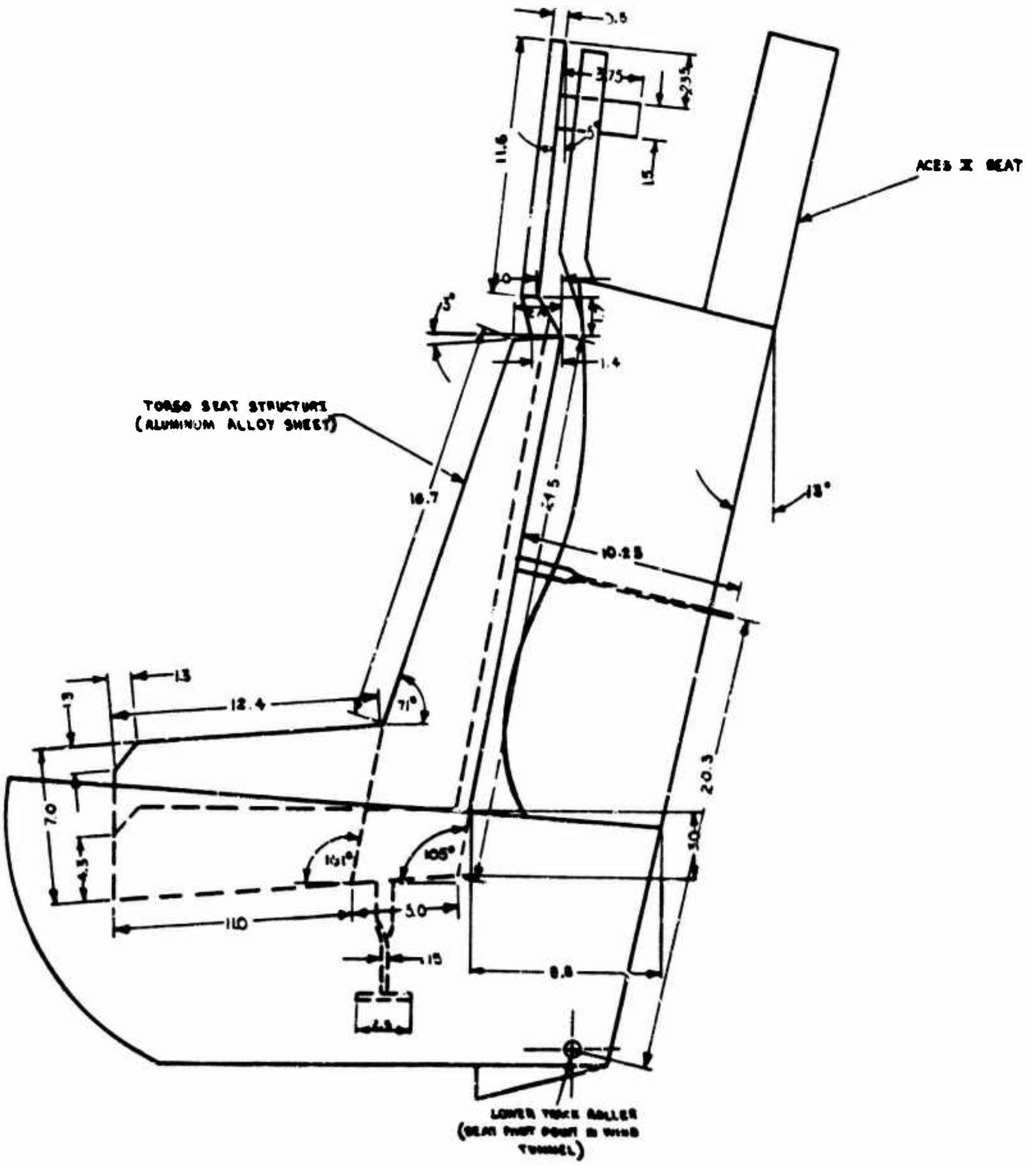


FIGURE 3(B). SIDE ELEVATION VIEW OF AN ACES-II EJECTION SEAT "LINER." THE DIMENSIONS ARE IN INCHES.

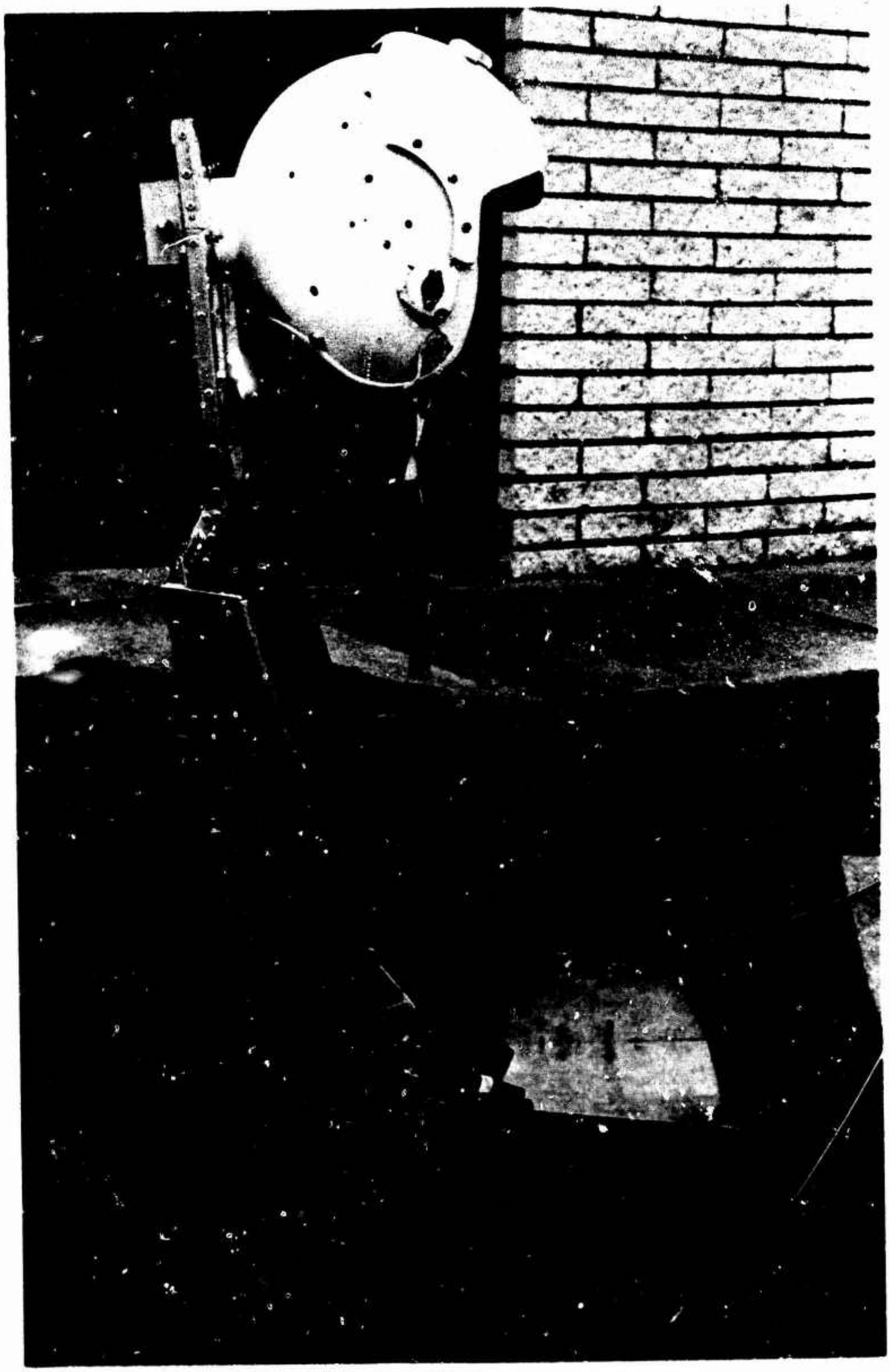


FIGURE 4. SIDE VIEW OF ACES-II EJECTION SEAT LINER, WITH HELMET ATTACHED.

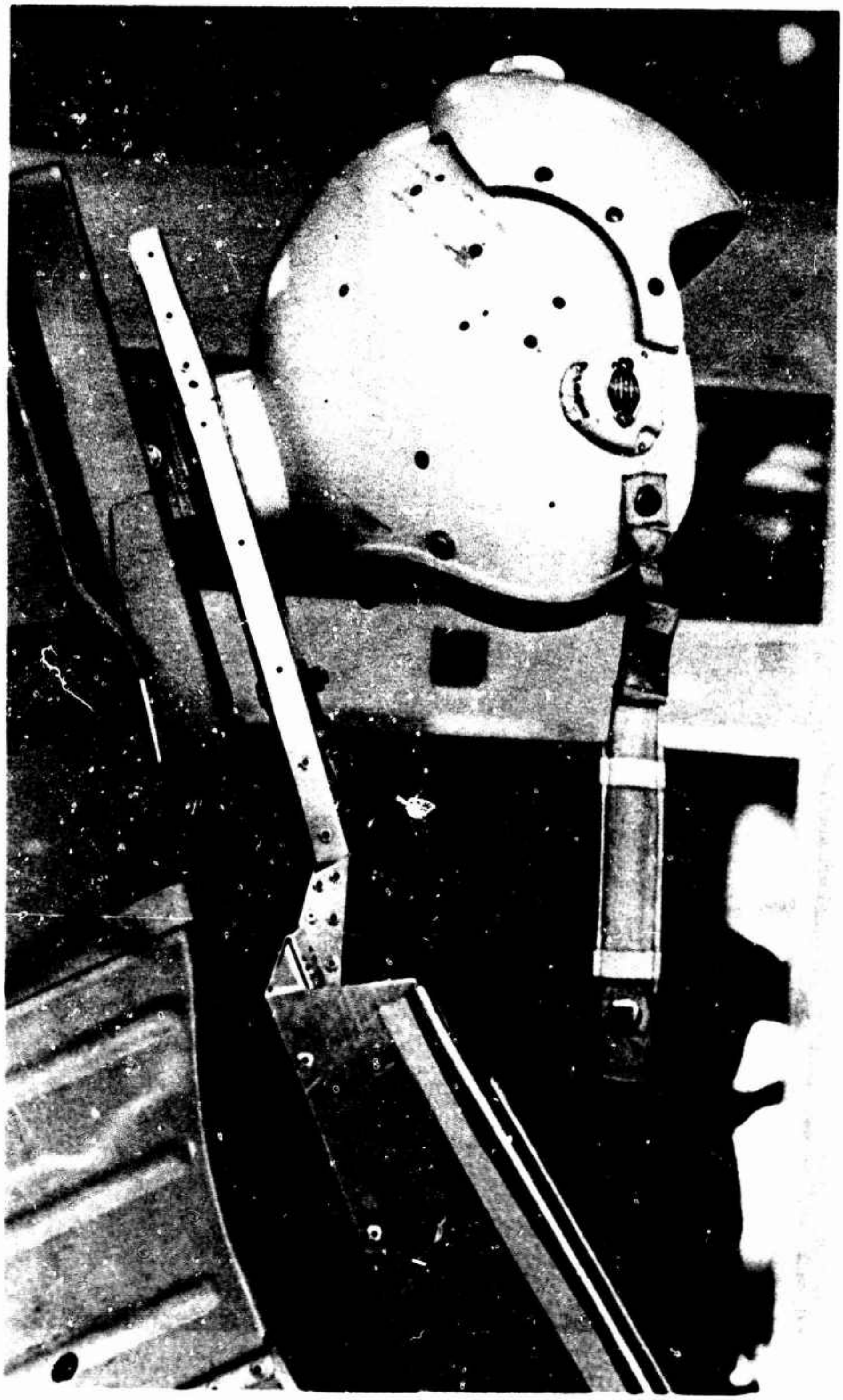


FIGURE 5. DETAIL OF HELMET ATTACHMENT TO LINER.

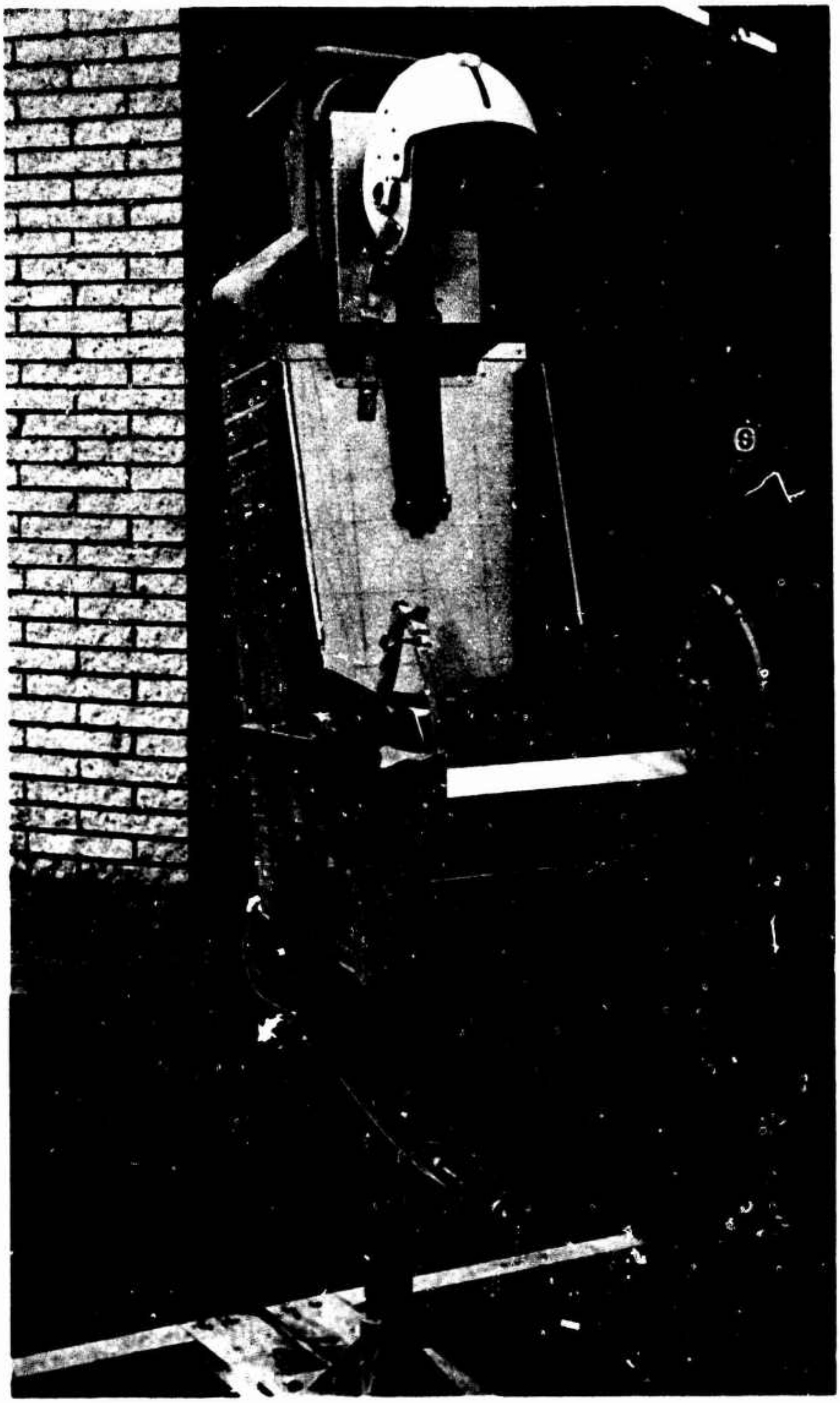
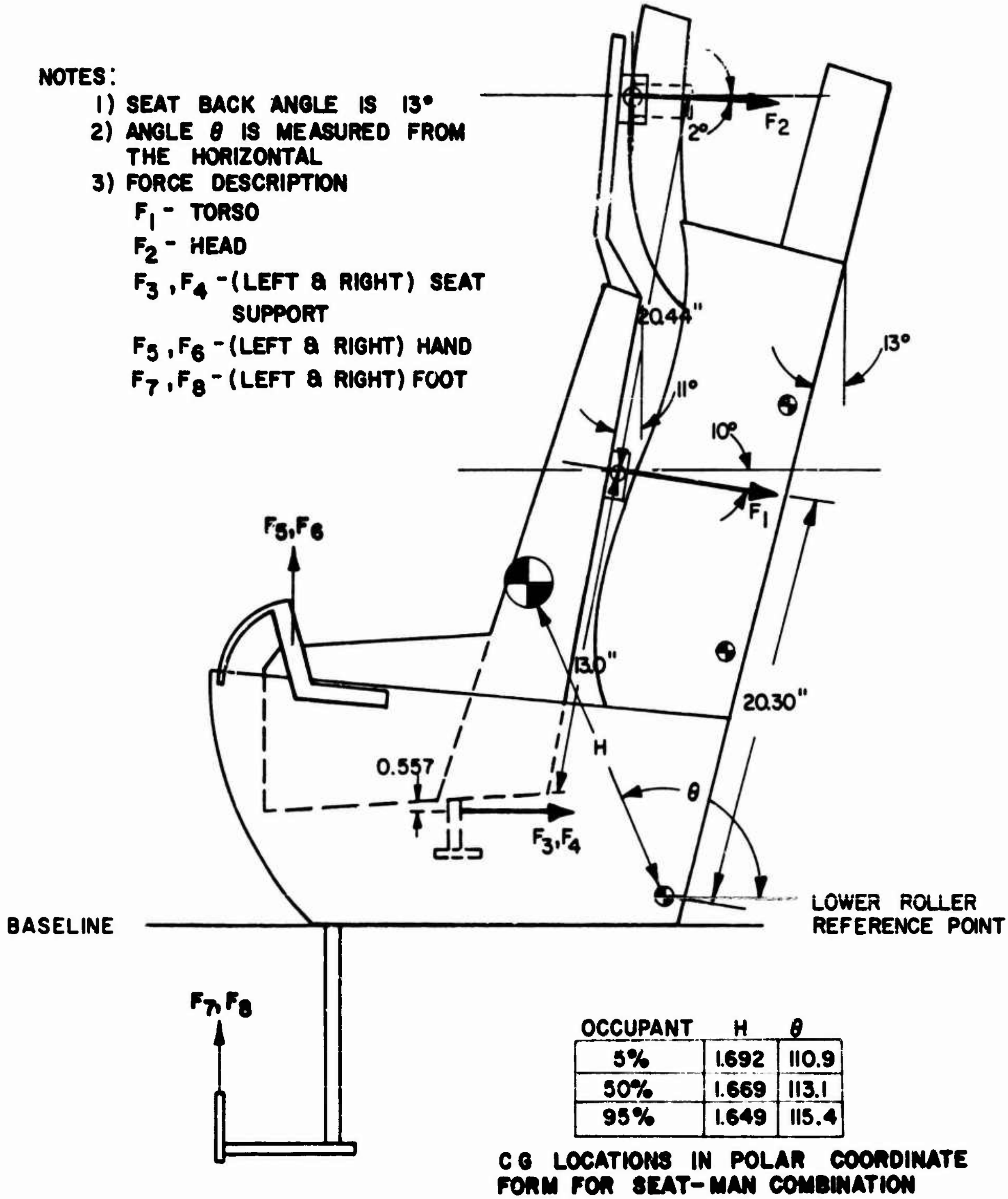


FIGURE 6. OVERALL VIEW OF ACES-II EJECTION SEAT SHOWING INSTALLATION OF LINER, HELMET, EJECTION HANDLES AND FOOT SUPPORTS.



OCCUPANT	H	θ
5%	1.692	110.9
50%	1.669	113.1
95%	1.649	115.4

CG LOCATIONS IN POLAR COORDINATE FORM FOR SEAT-MAN COMBINATION

FIGURE 7. SCHEMATIC OF FORCE CELL LOCATIONS AND CRITICAL INSTALLATION DIMENSIONS.

RESULTS AND DISCUSSION

Wind Tunnel Measurements of Limb and Torso Forces

The ACES-II seat was modified by installing a small "liner" seat pan and back, as shown in Figures 3 - 6, so that drag direction forces between the main seat and its occupant could be measured. Strain-gauged beams were also mounted to measure "hand-up" forces at the handles and "foot-up" forces on the footrests.

The seat was installed in the wind tunnel on Monday, August 11, and data collected using Fred W. Hawker as subject. Mr. Hawker is approximately 50 percentile, his statistics being

- Height: 5 ft 8 in
- Weight: 165 lbs
- Age : 27 years

The data is presented in Figures 8 - 16.

The torso drag and moment data are given in Figures 8 and 9. The drag data is added to the hand back and foot back data of Reference 1 and compared with the total seat plus occupant data of Reference 2 in Figure 10. About 80 percent of the total drag acts on the seat occupant at small trim angles, the ratio falling to about 50 percent at the high trim angles.

The moments of Figure 9 are not comparable with previously obtained total moment data because only forces in the drag direction were measured. Significant contributions could be made by the force distribution on the seat pan.

The "hand-up" forces are given in Figures 11 - 13 and the "foot-up" forces in Figures 14 - 16. The hand-up forces show a consistent decrease in magnitude with pitch angle. The maximum lift force occurs at approximately zero degrees angle of attack. The foot-up force shows an increase with angle of attack. These quantitative results confirm earlier observations by Major Ray Madson of the lifting effect on the legs at high angles of attack.

Discussion of Seat and Occupant Ballistic Coefficients

A_1 = occupant drag area

A_2 = seat drag area

$$m_1\dot{u}_1 = A_1 \tfrac{1}{2}\rho u^2$$

$$m_2\dot{u}_2 = A_2 \tfrac{1}{2}\rho u^2$$

$$\therefore \quad \frac{\dot{u}_2}{\dot{u}_1} = \frac{\text{seat deceleration}}{\text{occupant deceleration}} = \frac{A_2}{A_1}\frac{m_1}{m_2}$$

ACES-II seat weight 81 pounds, occupant weight 165 pounds

From Figure 10

$$\frac{A_1}{gm_1} = \frac{5.3}{165} = .032$$

$$\frac{A_2}{gm_2} = \frac{(6.6 - 5.3)}{81} = .016$$

$$\therefore \quad \frac{\dot{u}_2}{\dot{u}_1} = \frac{.016}{.032} = \frac{1}{2}$$

Thus the occupant has, in this position, twice the deceleration potential of the seat. Doubling the seat drag area by adding 1.3 ft^2 would equalize the decelerations. A drag area greater than 1.3 ft^2 would result in a tension force between the man and seat.

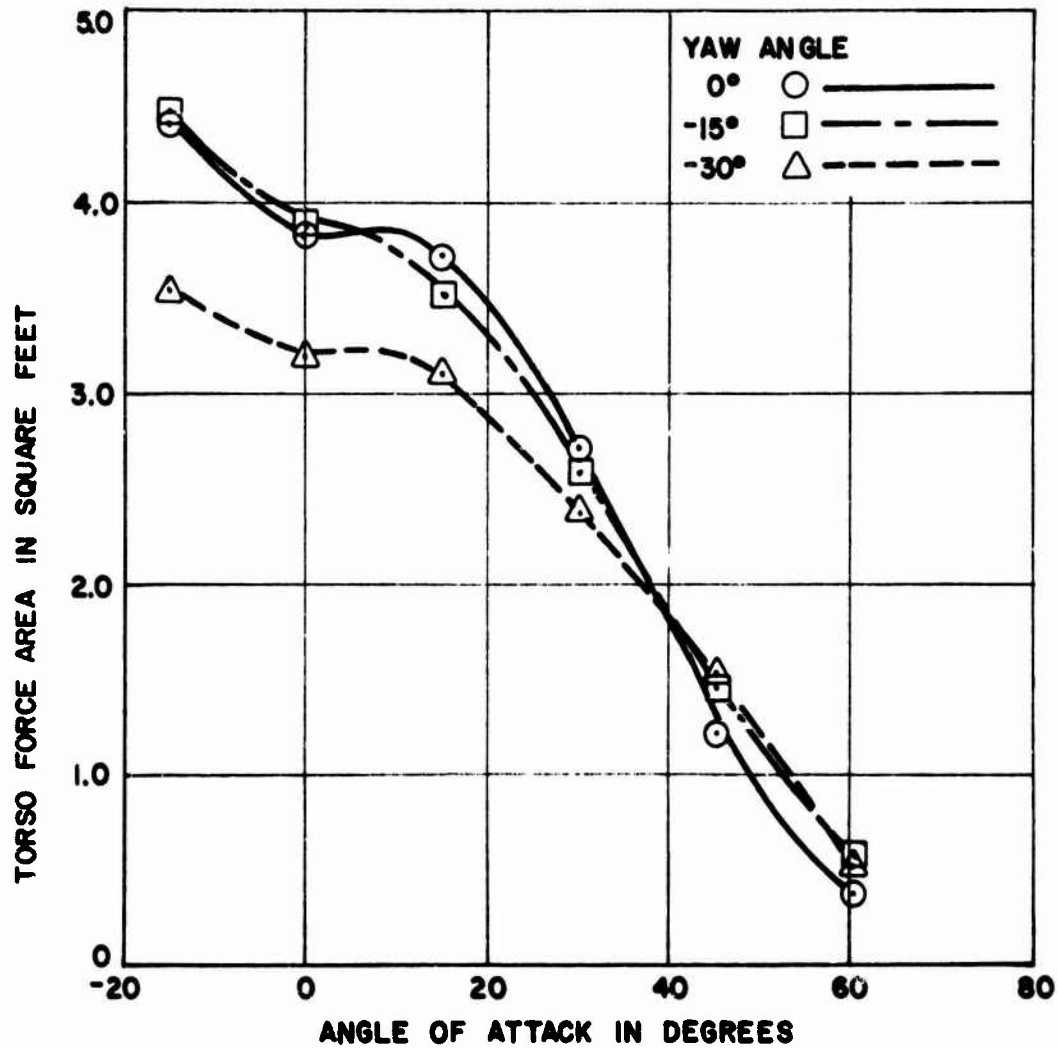


FIGURE 8. TORSO FORCE AREA AS A FUNCTION OF ANGLE OF ATTACK FOR THE ACES-II EJECTION SEAT.

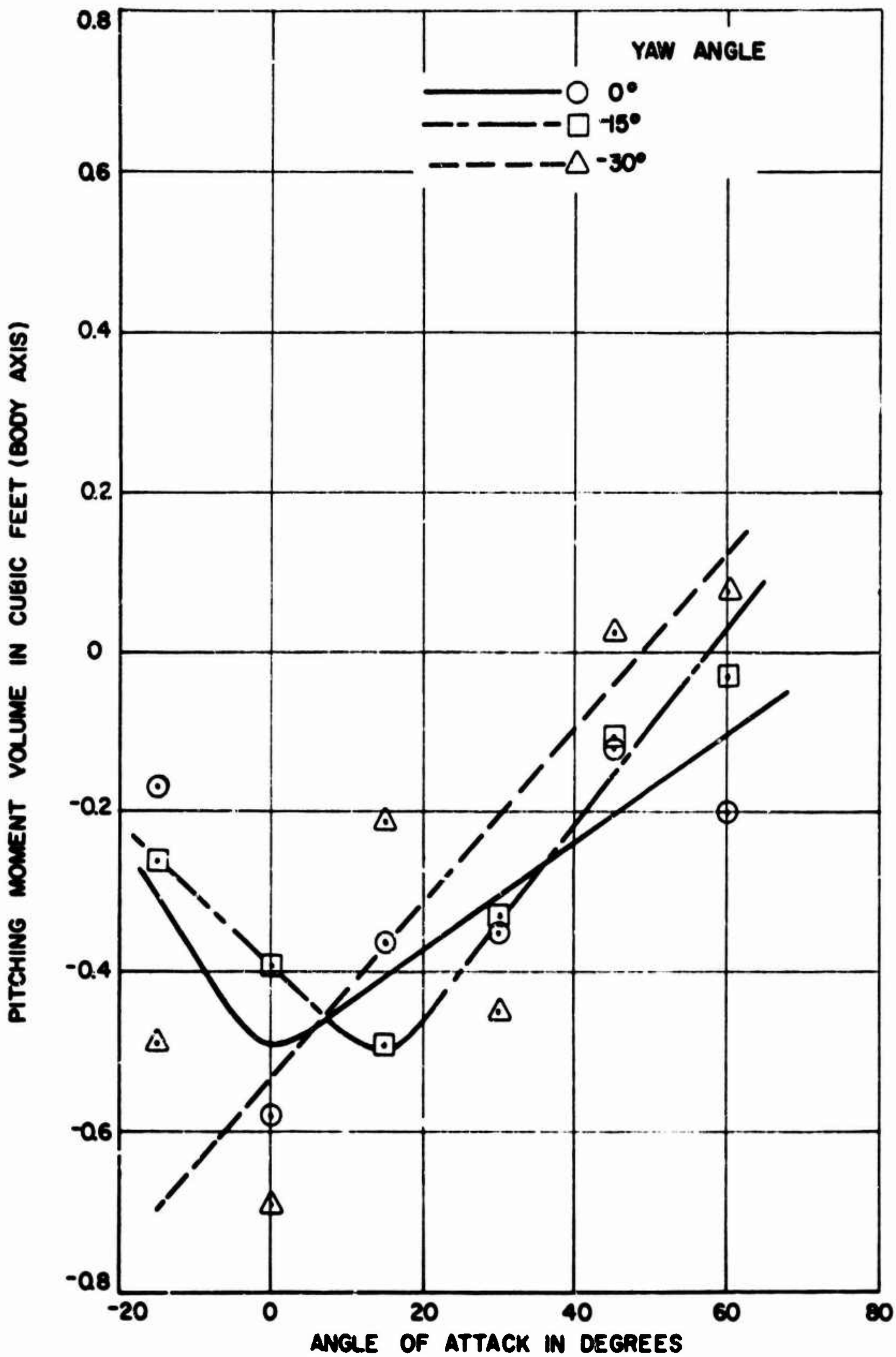


FIGURE 9. PITCHING MOMENT VOLUME OF THE TORSO WITHIN THE ACES-II EJECTION SEAT AS A FUNCTION OF PITCH ANGLE, ABOUT THE CENTER OF GRAVITY DEFINED FOR A 50% MAN IN FIGURE 7.

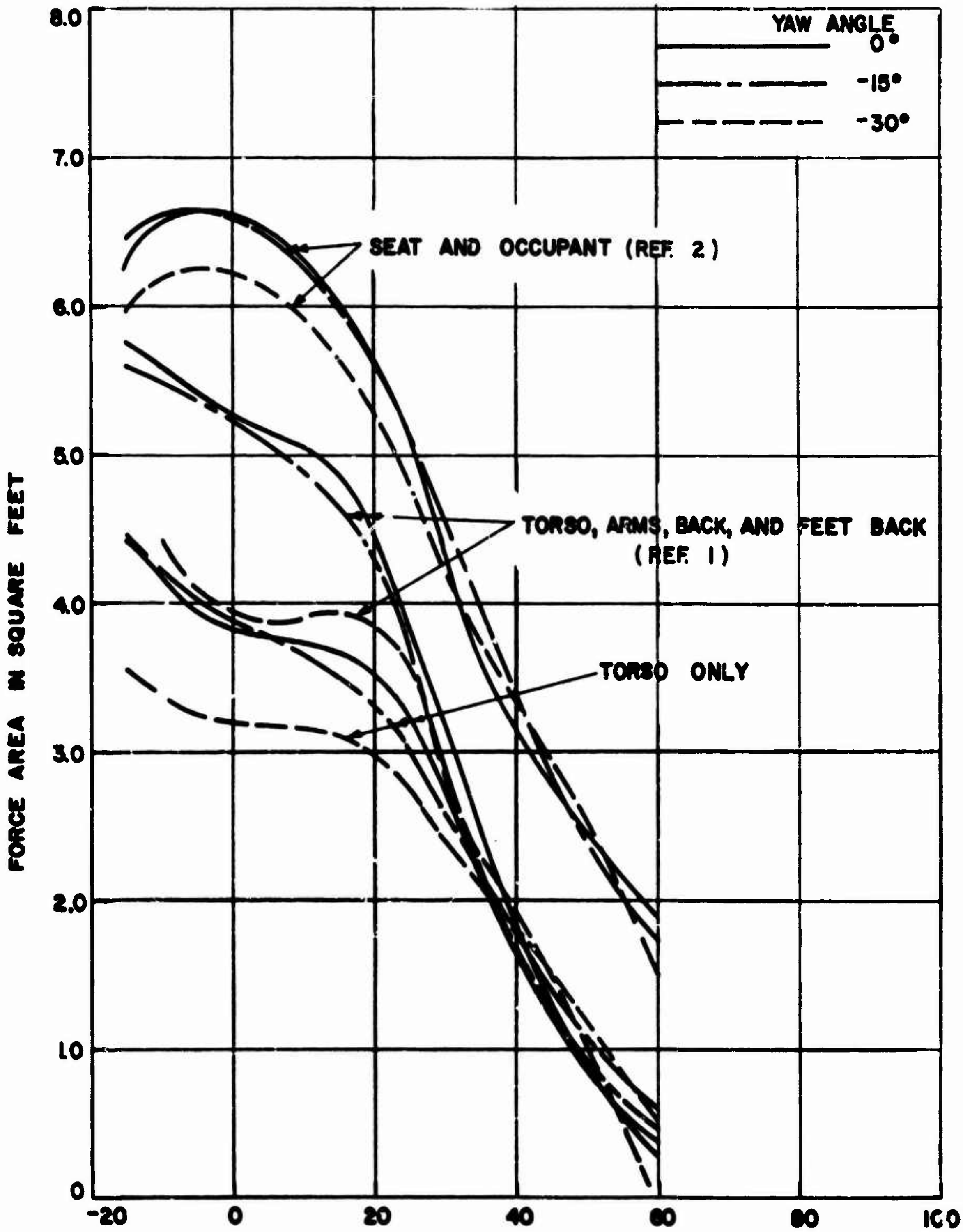


FIGURE 10. COMPARISON OF SEAT PLUS OCCUPANT AND TORSO PLUS LIMB DRAG AREAS FOR ACES-II EJECTION SEAT.

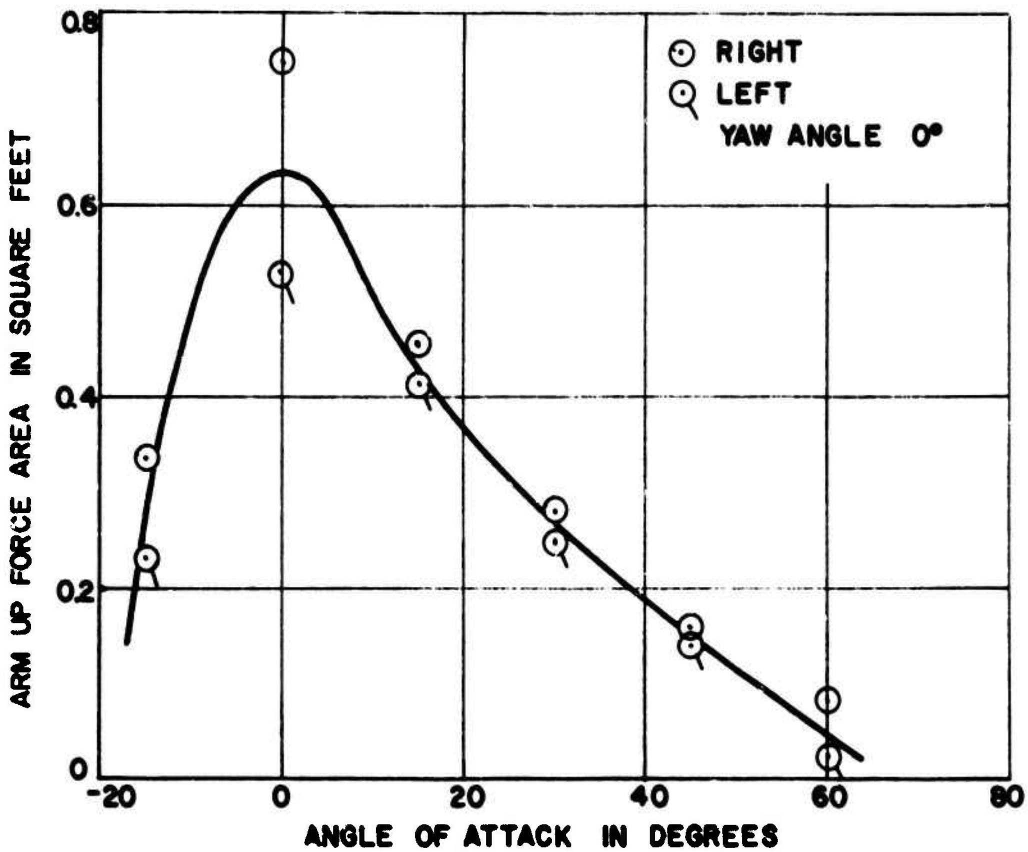


FIGURE 11. ARM-UP FORCE AREA AS A FUNCTION OF ANGLE OF ATTACK FOR THE ACES-II EJECTION SEAT (YAW ANGLE, 0°).

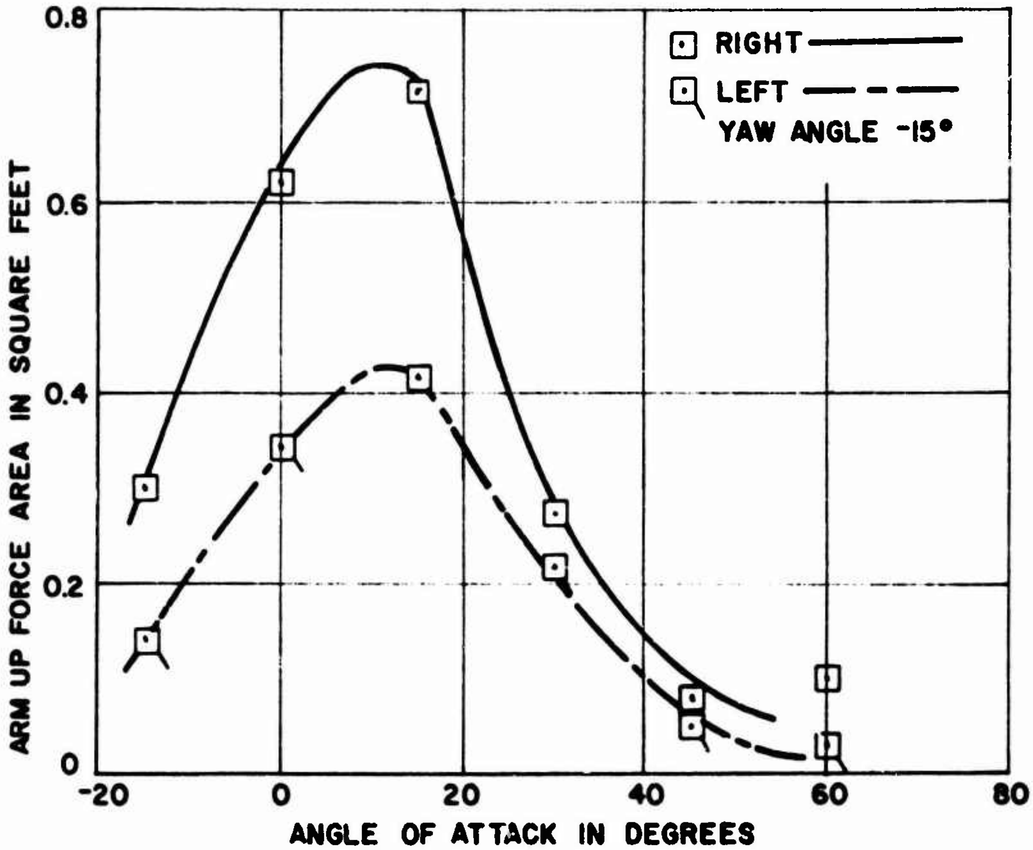


FIGURE 12. ARM-UP FORCE AREA AS A FUNCTION OF ANGLE OF ATTACK FOR THE ACES-II EJECTION SEAT (YAW ANGLE, -15°).

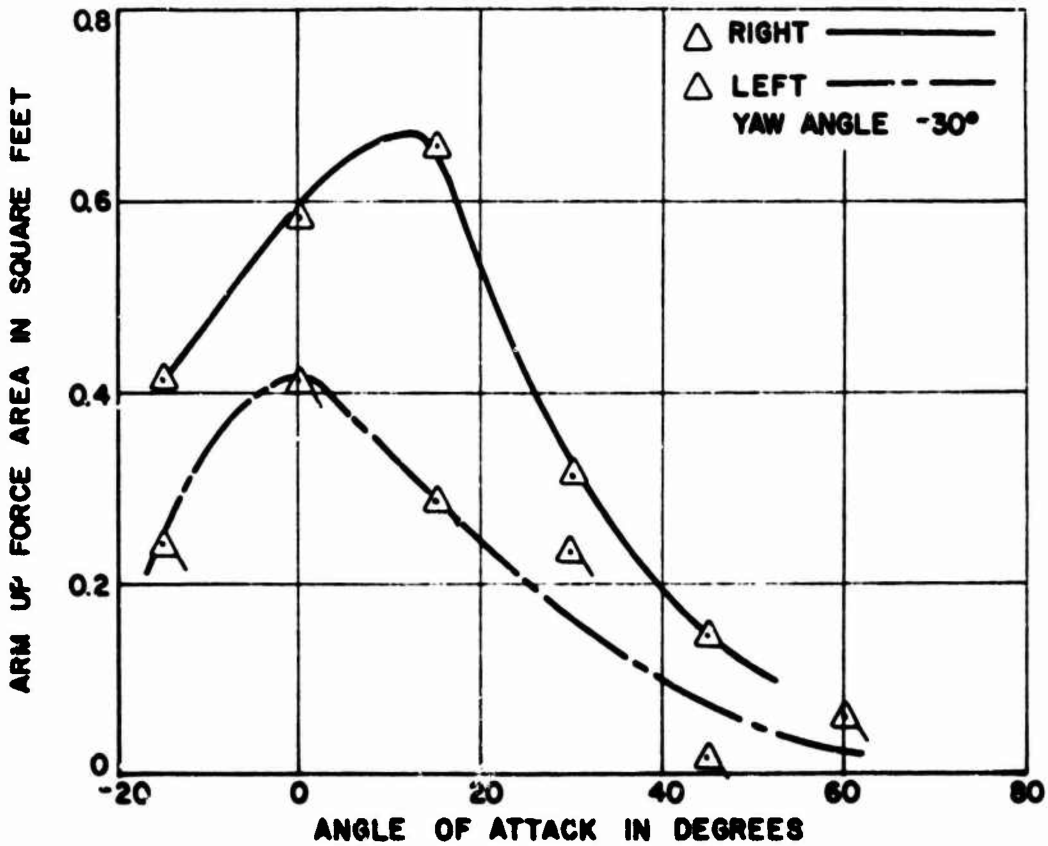


FIGURE 13. ARM-UP FORCE AREA AS A FUNCTION OF ANGLE OF ATTACK OF THE ACFS-II EJECTION SEAT (YAW ANGLE, -30°)

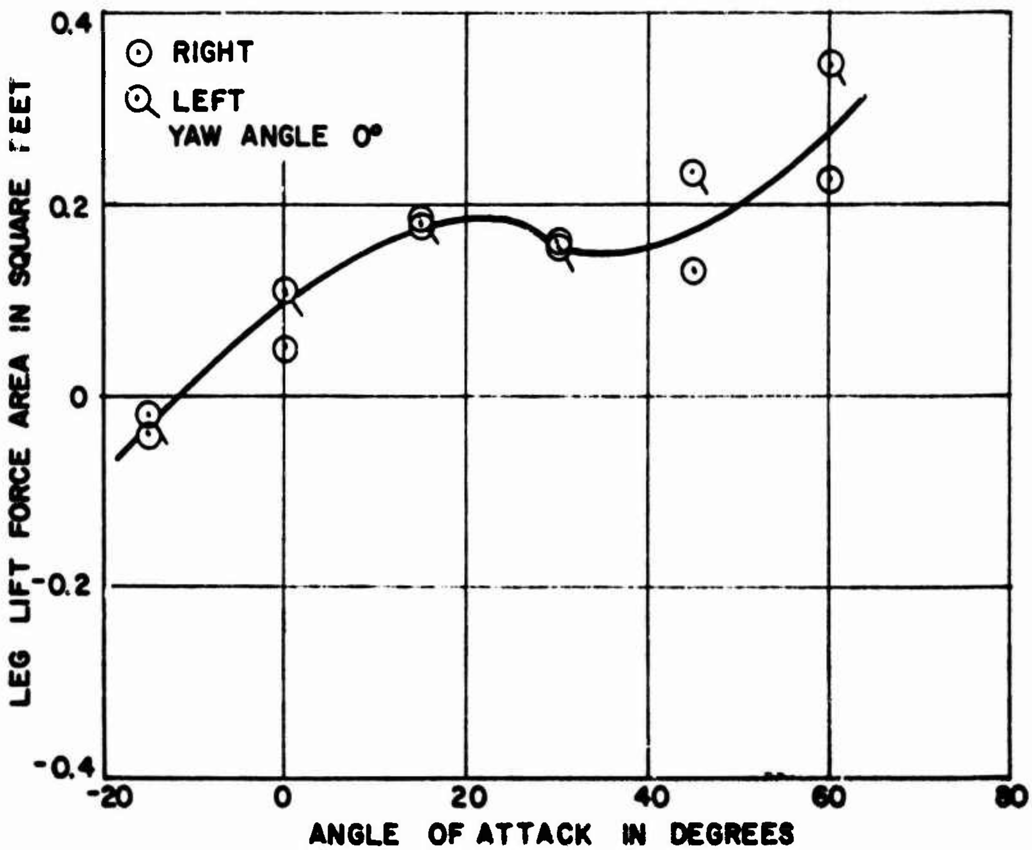


FIGURE 14. LEG-LIFT FORCE AREA AS A FUNCTION OF ANGLE OF ATTACK FOR THE ACES-II EJECTION SEAT (YAW ANGLE, 0°).

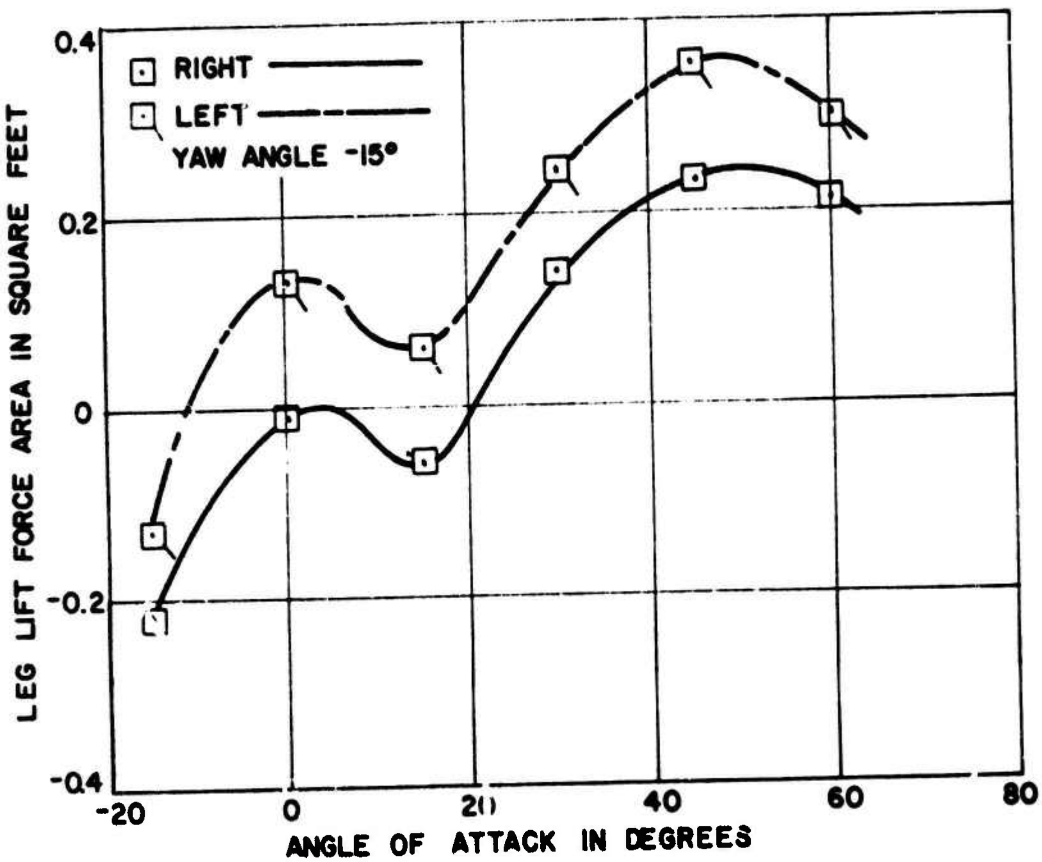


FIGURE 15. LEG-LIFT FORCE AREA AS A FUNCTION OF ANGLE OF ATTACK FOR THE ACES-II EJECTION SEAT (YAW ANGLE, -15°).

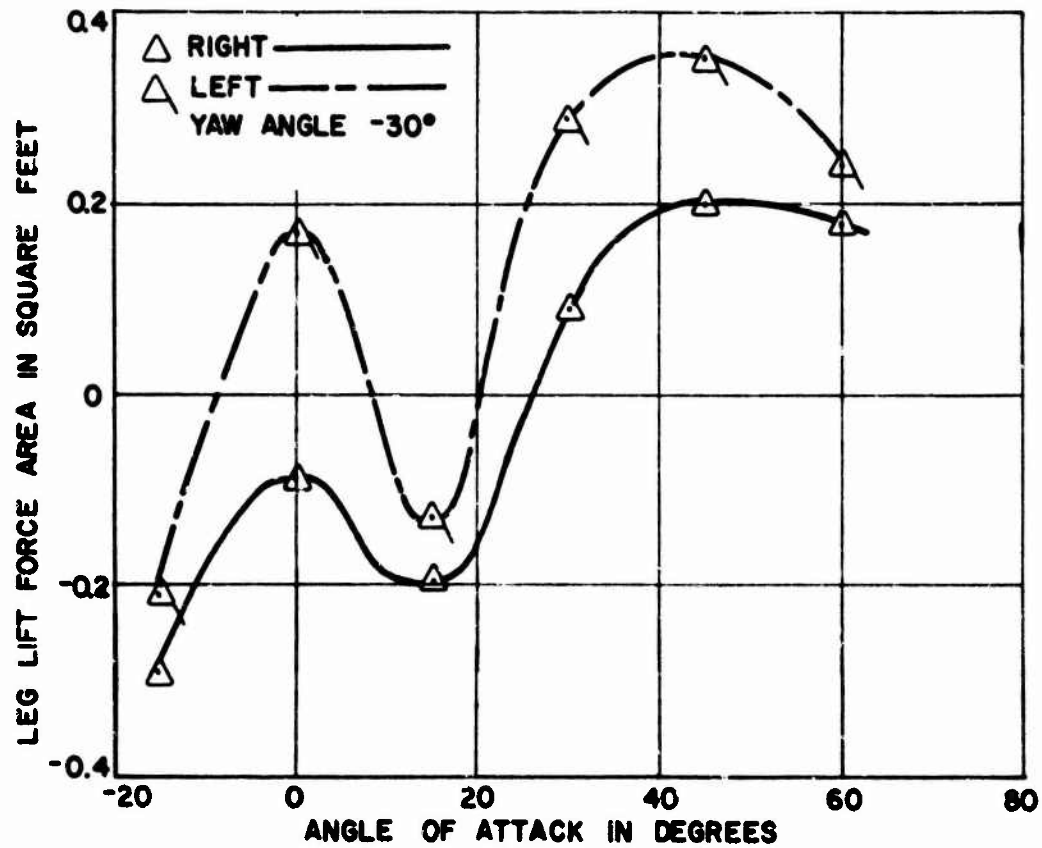


FIGURE 16. LEG-LIFT FORCE AREA AS A FUNCTION OF ANGLE OF ATTACK FOR THE ACES-II EJECTION SEAT (YAW ANGLE, -30°).

CONCLUSIONS

1. The occupant of the ACES-II ejection seat experiences about 80 percent of the total drag forces of the seat plus occupant, at small pitch angles. The percentage falls with increasing pitch angle.

2. Hand-up forces decrease with increasing pitch angle up to 60° pitch angle for the ACES-II ejection seat.

3. Feet-up forces increase with increasing pitch angle up to 60° pitch angle for the ACES-II ejection seat.

4. The difference in drag area between the occupant and seat in the tested configuration would cause a compressive force, thus hindering the separation of the occupant from the seat.

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